Cover Story

Part 1

Storage Tanks: Snapshots of Failures, Damages and Inspections

Lessons learned from past failures provide insight and know-how needed to inspect and operate storage tanks reliably

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IN BRIEF

- ROOF CHALLENGES
- WELDING THE DRAIN NOZZLE IN LARGE TANKS
- CRACK IN THE FLOOR-TO-WALL JOINT
- FIBER-REINFORCED PLASTIC SEPTIC TANKS
- NON-INTRUSIVE NON-DESTRUCTIVE TESTS
- ROBOTICS

Storage tanks are a common sight at many facilities of the chemical process industries (CPI). Tanks are part of our everyday life and they appear deceivingly simple. However, they require a great deal of know-how and specialized knowledge to operate reliably. Otherwise, failures can occur.

Some tank failures are well known by the public, as the following examples show:

- In 1919, an accident involving a distilling tank with molasses killed 21 persons in Massachusetts [*1*]
- In the 1984 Bhopal tragedy, people were exposed to methyl isocyanate gas, resulting in 3,787 or more deaths [*2*]
- In 2001, when a sulfuric-acid storage-tank failure in Delaware City, Delaware [*3*] resulted in one person's death, eight others injured and significant damage to aquatic life

Although the damage and failures discussed in this article have had less impact than these well-known examples, they underline that a great deal of know-how and attention to detail are needed to operate storage tanks reliably. The tank incidents presented are the following:

- Roof challenges
- Welding the drain nozzle in large steel tanks
- Crack in the floor-to-wall joint
- Know-how for installing fiber-reinforced plastic septic tanks
- Non-intrusive non-destructive tests

Roof challenges

Fixed-roof tanks are designed to fail at the shell-to-roof weld. A fixed-roof tank exploded while personnel were refurbishing equipment upstream of the tank. The roof was torn off and one of the persons working upstream was severely injured.

The work upstream had resulted in a pressure surge. The vents were supposed to allow the pressure to blow off, but the sudden pressurization was such that the undersized vent could not transfer gases quickly enough. The failed tank roof-to-shell weld had a torn, overloaded appearance. It appeared to be free of pre-existing flaws. The pressure at which the roof separated was estimated to be 0.6 psi. This value appeared to be low, but many tanks are constructed according to API Standard 650 "Welded Tanks for Oil Storage." Such tanks intentionally have a weak roof-to-shell seam so that if an internal overpressure from an explosion or a similar situation develops, the design allows the roof to separate from the vertical shell to prevent failure of the bottom seams and the tank's "rocketing" or propelling upward [*4*].

Fixed-roof condition after removing in-

FIGURE 1. After removing the insulation, this tank roof showed numerous openings

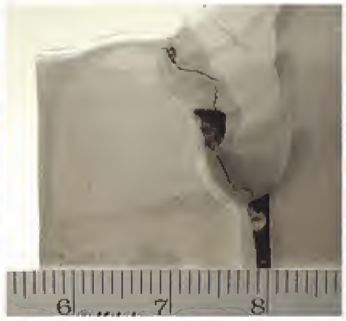

FIGURE 2. Cracks were observed in this tank shell-to-nozzle weld

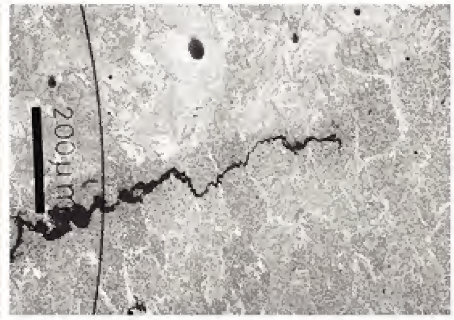

FIGURE 3. A closeup of the tank shell-to-nozzle fillet weld crack shown in Figure 2

sulation. After removing the insulation from a roof, inspection personnel identified numerous through-thickness openings in the roof (Figure 1).

Lesson learned about fixed-roof tanks. Do not walk on the roof without significant hazard diminishing strategies.

Welding the drain nozzle in large tanks

During hydrostatic testing, an NPS 3 (nominal pipe size) tank drain nozzle leaked. The tank was fabricated to hold diesel fuel. The drain nozzle had one fillet weld joining it to the shell and another joining it to a reinforcing pad (repad), which is a plate formed to the shape of the tank or vessel around a nozzle for extra strength. The welds had multiple cracks, porosity and non-fusion, as can be seen in Figures 2 and 3.

Lesson learned about welding the drain nozzle in steel tanks. Tanks are welded from the floor up. This means that access to this location (the drain) for welding is challenging. To prevent leaks, the welding passes can be deposited in multiple stages to prevent the formation of continuous leak paths. The hold times for the hydrostatic test should meet and exceed the standard requirements. Fluorescent liquid penetrant could make identifying a minute leak easier.

FIGURE 4. Shown here is the tank shell-to-bottom joint. Note the occurrence of soil settlement and tank wall distortion

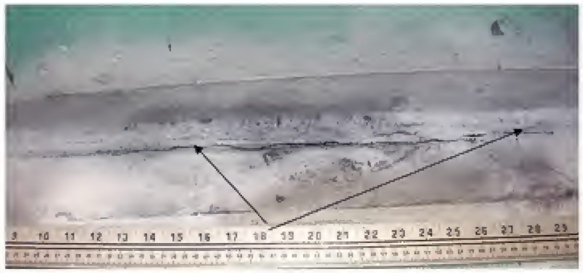

FIGURE 5. Cracks of the tank wall of Figure 4 are identified with magnetic particles

FIGURE 6. For the same tank shown in Figure 4, this metallographic cross-section of the tank floor shows Intergranular cracks with oxides/corrosion products

Crack in the floor-to-wall joint

A fertilizer service carbon-steel tank floor developed cracks in the tank wall to tank bottom joint, as shown in Figures 4 and 5. The cracks had the following characteristics:

- The cracks developed in the cross-section with the highest stresses in the storage tank. Hydrostatic and welding residual stresses are maximum on this joint
- The cracks had some oxides/corrosion products (see Figures 6 and 7)
- The cracks were intergranular

These characteristics are consistent with the cracks being due to nitrate stress corrosion cracking (SCC). Additional stresses from the soil settlement under the tank resulted in distortion of the tank wall and floor. These stresses further contributed to the cracks forming.

Lesson learned about the tank floor-to-wall joint. Soil settlement needs to be monitored, and this critical joint (for carbon steels) needs inspection techniques, such as magnetic particles or eddy current, or both.

Fiber-reinforced plastic septic tanks

New, deep-underground fiber-reinforced plastic (FRP) spiral-wound tanks had water ingress while the ground was being excavated. Prior to the inward leaks, the grade for the deep underground tanks had experienced a sudden increase in water level due to rain. The rain resulted in the tanks lifting partially (due to buoyancy) from their excavated installation grade.

Examining the tanks from the inside, the shape was oval (Figure 8). Also, many of the joints were "whitened." "Whitening" can develop when FRP is subjected to localized stresses (Figure 9). These damages suggested the tanks had experienced excessive compressive displacement during their partial lift.

The summer excavation held several surprises, as follows:

- The soil surrounding the tanks had 0.3 m × 3 m × 0.1 m chunks of ice (Figure 10). Some of these ice chunks had been pressing against the tank shell. FRP is prone to cracking when subjected to localized compressive loads
- The day before the author left the site, an intermittent underground stream was noted a couple of meters below the ground level. The flow was directed at the tanks and would have eroded the ground and support for the tanks, once installed

The damaged tanks were replaced. Soil, in accordance to strict (and necessary) installation guidelines, was used to install the replacement tanks. The flow of the underground stream was diverted away from the tanks. The replacement tanks were installed without further surprises.

Lesson learned about installing FRP septic tanks. Buried FRP tanks require special installation practices heralded by their suppliers. Thorough evaluations of the soil con-

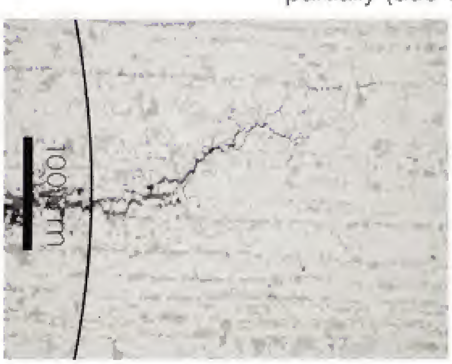

FIGURE 7. Another view of the metallographic cross-section of the tank floor (Figure 6), which shows Intergranular cracks (2% Nital etch)

FIGURE 8. This septic tank's inside diameter was oval. The internals had separated from the shell

FIGURE 9. For the same septic tank of Figure 8, many of the inside joints had whitened — an indication of localized stress

FIGURE 10. During a summer excavation, large chunks of ice were identified surrounding the septic tank of Figure 8

FIGURE 11. Tank floor pits are identified with acoustic emission non-destructive testing

FIGURE 12. Using robotics for visual and coating inspections can reduce the need for personnel to enter confined spaces

ditions, underground water, grading and installation are musts.

Non-intrusive non-destructive tests

Acoustic emission (AE) testing of FRP and of ammonia tanks. AE tests of FRP and ammonia tanks provide volumetric tests of shells of the tanks while in service. Entry is not required, avoiding the potentially damaging process of shutting and exposing the tanks to air (when ammonia tanks can develop stress cracks) and thermal stresses for ammonia service. The tests aim to detect and locate areas of concern. Figure 11 shows tank bottom pits identified with acoustic emission. Follow-up inspection with a complementary non-destructive testing (NDT) method is needed to identify and size any AE indications for ammonia steel tanks. FRP tanks require visual follow-up.

This technology was proven and implemented by Monsanto personnel. As stated by the author's colleague, Martin Peacock (now retired), "the initial round of testing led to shutting down several tanks for inspection and repair of fabrication defects detected by the AE test. However, once the tanks were repaired, no further inspections were required. One tank in the U.S. has been in continuous service with regular AE testing since 1984. This tank is tested every five years with the last carried out in June 2011 with no indication of service related damage to the shell" [5].

Lesson learned about non-intrusive AE testing of ammonia tanks. Used wisely, these tests can keep FRP and ammonia tanks operating reliably without causing inspection-related tank damage.

Robotics

Today, we are performing robotic inspections to monitor the thickness of tank shells and roofs. Robotics are also used to inspect water tanks. The future holds the promise of robotics being used for tank thickness, visual and various other internal inspections for multiple other services (Figure 12). This would reduce the need for personnel to enter confined spaces and the time and budgets needed for emptying and storing tank contents elsewhere. However, cleaning and navigational challenges are today the obstacles that need to be overcome. ■

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